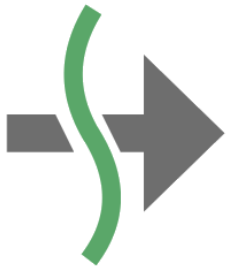
CMPS 312

Coroutines for Asynchronous Programming



Dr. Abdelkarim Erradi

CSE@QU

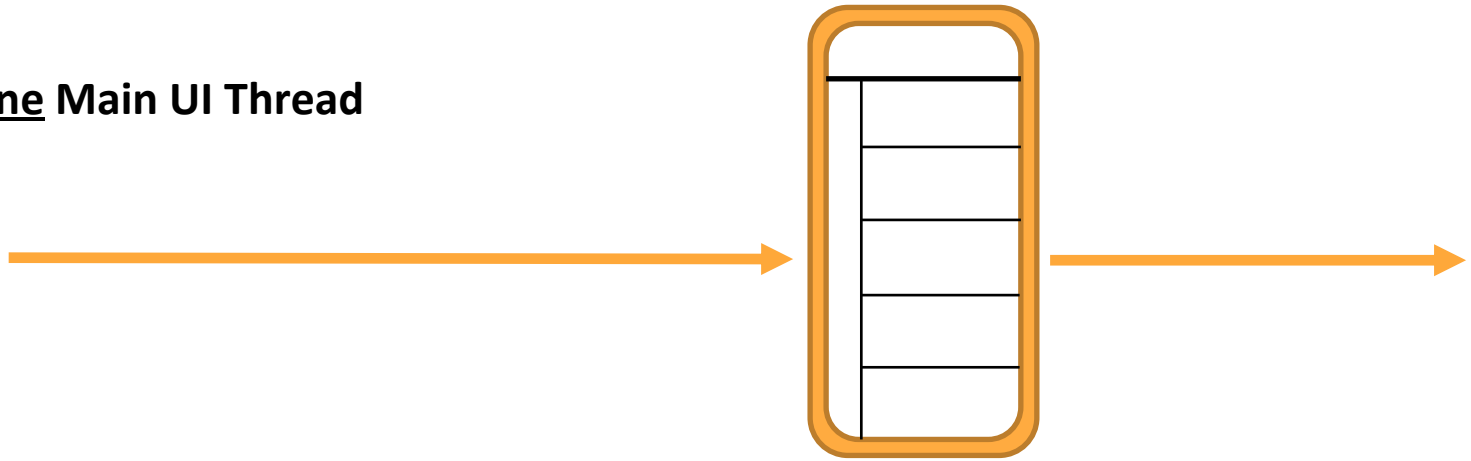
Outline

1. Coroutines Basics
2. Coroutines Programming Model
3. Coroutine Cancelling
4. Exception Handling

Coroutines Basics

User Interface Running on the Main Thread

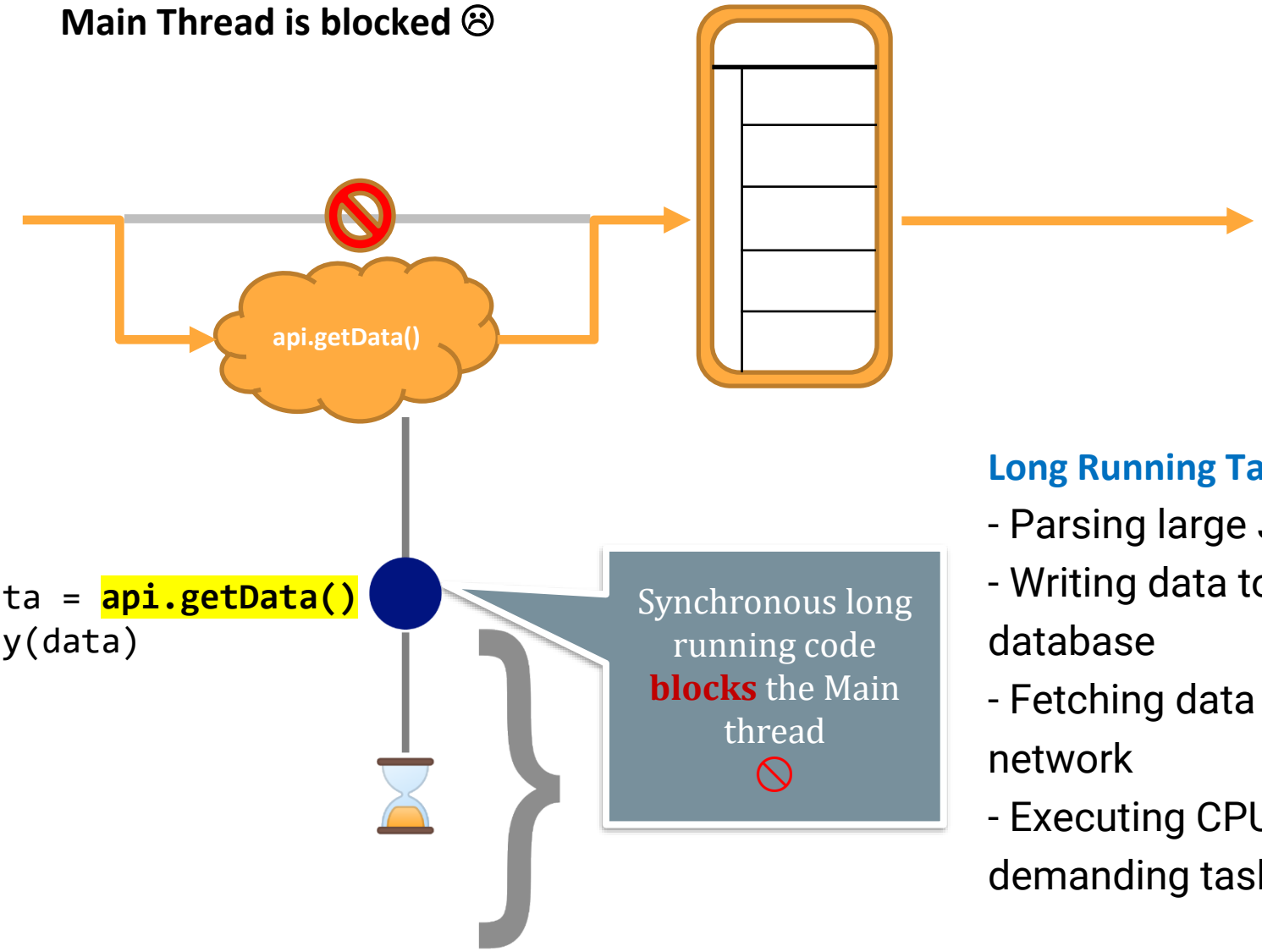
One Main UI Thread



To guarantee a great user experience, it's essential to **avoid blocking the main thread** as it used to handle UI updates and UI events

Long Running Task on the Main Thread

Main Thread is blocked ☹



Long Running Tasks include:

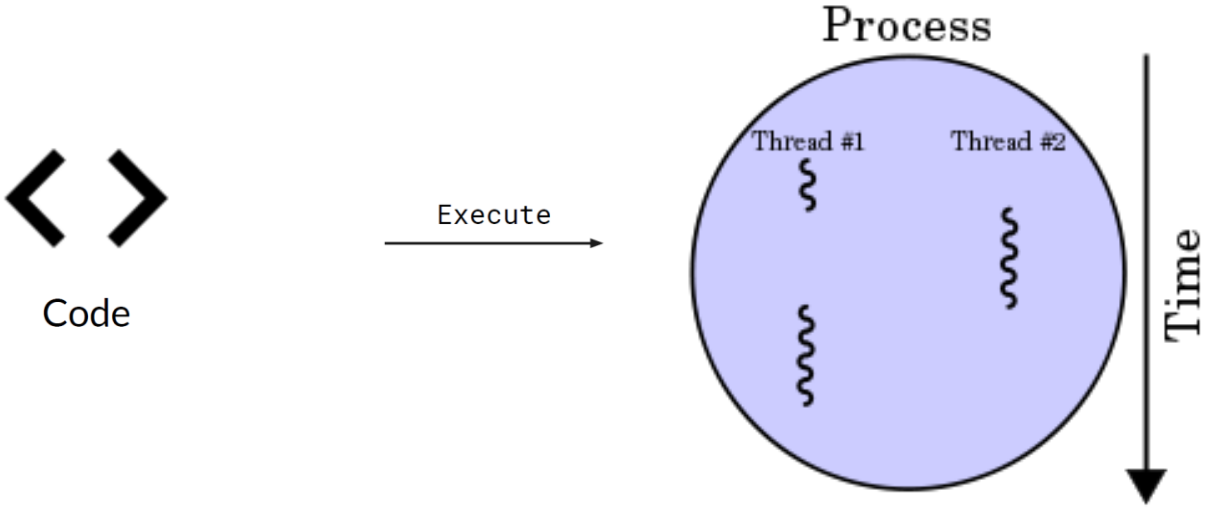
- Parsing large JSON file
- Writing data to a database
- Fetching data from the network
- Executing CPU demanding task

How to address problem of long-running task?

- How to execute a long running tasks without blocking the Main thread?

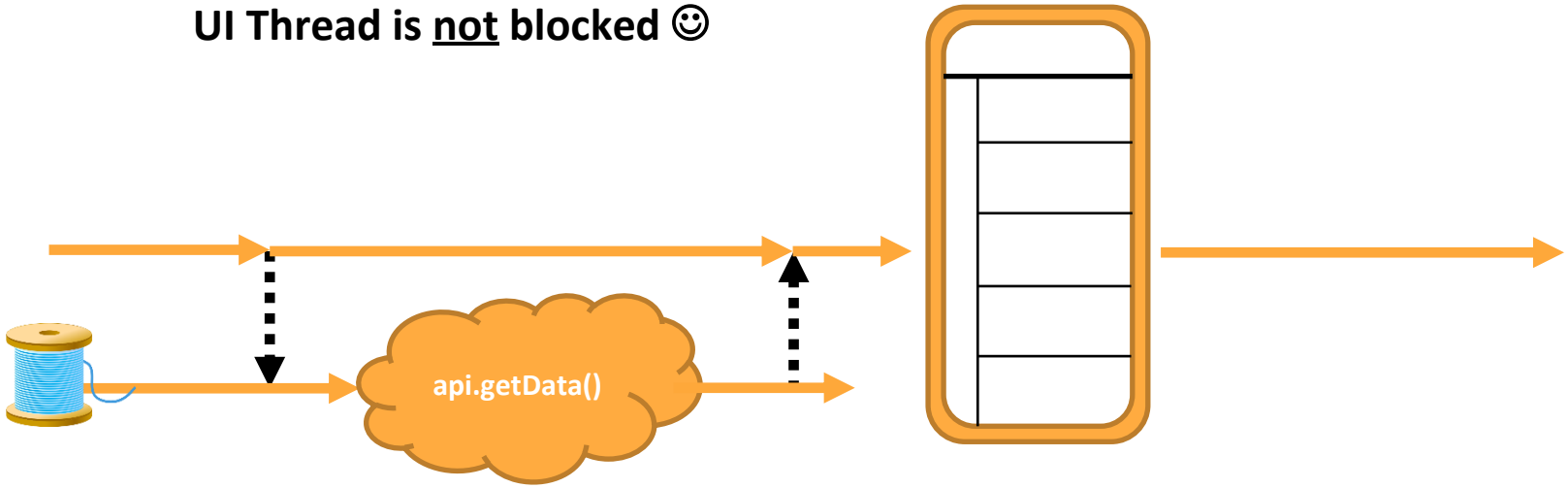
  => Solution 1: **Use multi-threading**

- A thread is the **unit of execution** within a process
  - It allows **concurrent** execution of tasks within an App



Solution 1 – Run Long Running tasks on a background thread

UI Thread is <u>not</u> blocked ☺




```
thread {
    val = result = api.getData()
}
```

- UI can only be accessed from the Main thread

- How to transfer the result from the background thread to the main thread?

How to transfer the result from the background thread to the main thread?

- By using callbacks, you can start long-running tasks on a background thread
- When the task completes, the callback is called to notify the main thread of the result

Limitations:

- Nested callbacks can become difficult to understand (aka **Callback Hell**)
- Difficult to cancel background tasks
- Difficult to run tasks in parallel
- Difficult to handle exceptions

Callback Example

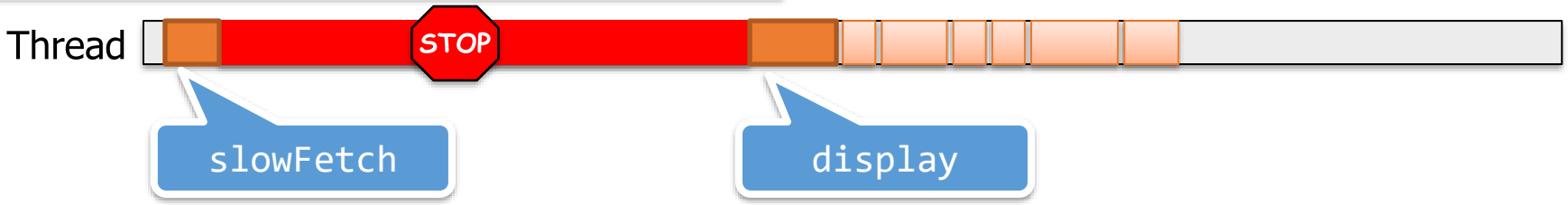
```
fun main() {
    // Call the function and pass callback function
    getUserOrders("sponge", "bob") { orders ->
        orders.forEach { println(it) }
    }
}
fun getUserOrders(username: String, password: String,
                  callback: (List<Order>) -> Unit) {
    login(username, password) { user ->
        fetchOrders(user.userId) { orders ->
            // When the result is ready, pass it to main using the callback
            callback(orders)
        }
    }
}
```

Callback hell = Nested callback functions are difficult to understand

Synchronous vs. Asynchronous Functions

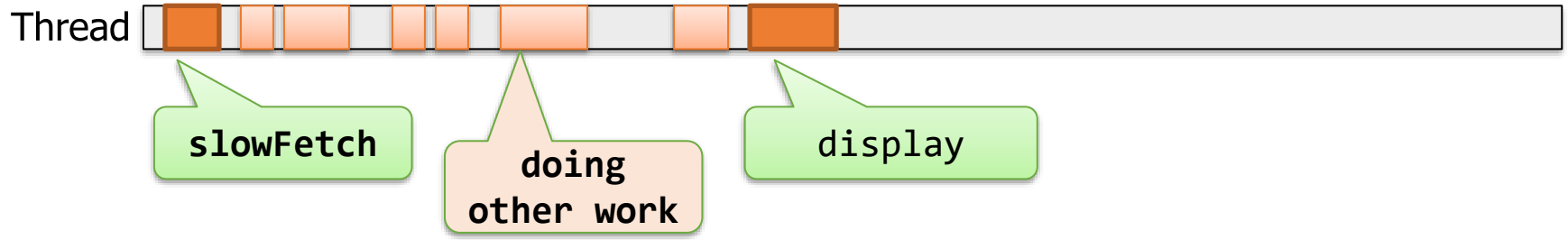
Synchronous (i.e. **Blocking**) → Wait for result before returning

```
val result = slowFetch(...) // UI Thread
display(result)  // UI Thread
```




```
// Slow request with callbacks
fun makeNetworkRequest(display: (Result) -> Unit) {
    // The slow network request runs on another thread
    slowFetch { result ->
       // When the result is ready, this callback will get the result
       display(result)
    }
}
```

Asynchronous (i.e. **Non-Blocking**) → do an **asynchronous** call to slowFetch using backgroud thread, then update UI with the result



UI not blocked

Thread Limitations

Threads are **costly** (occupy 1-2 mb)

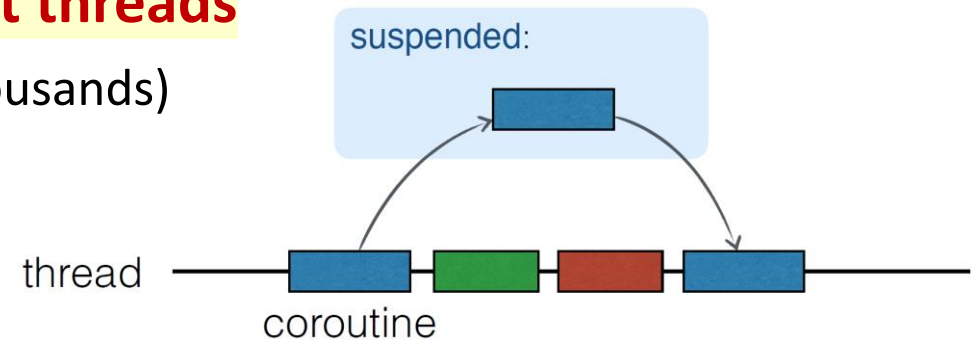
- Some **threads** are **special** (e.g. Main UI thread) and should not be blocked

Better alternative are **Coroutines**

- Coroutines are like light-weight threads

(very cheap and fast to create even thousands)

- Coroutine = computation that can be suspended then resumed



Thread is not blocked!

Why Coroutines?

Most mobile apps typically need:

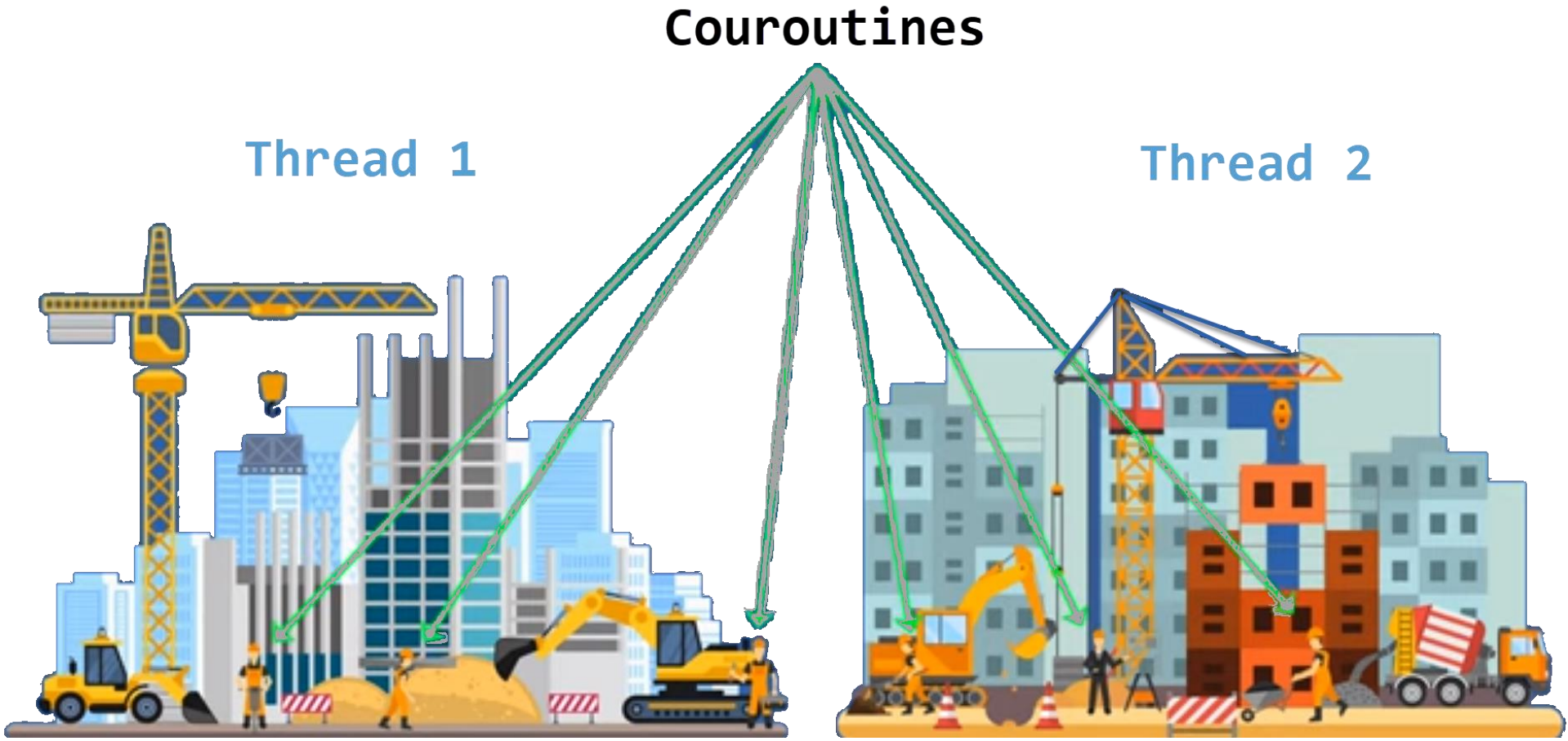
Call Web API (Network Calls)	Database Operations (read/write to DB)	Complex Calculations

Can use coroutines to offload long-running computations or Asynchronous I/O operations

What distinguishes Coroutines from Threads?

1. Coroutines are like **light-weight** threads. They are more efficient and yield better performance
   - Multiple coroutines can run within a thread
1. Easier **cancellation** of a long running coroutine
2. Easier **exception handling**
3. Easier to **run coroutines in parallel** to improve the app performance
4. Easier to **switch the coroutine execution between threads**
   - e.g., do a Network call using the IO Thread then switch to the Main thread to update the UI
5. Easier **asynchronous** programming
   - Replace callback-based code with sequential code to handle asynchronous long-running tasks without blocking

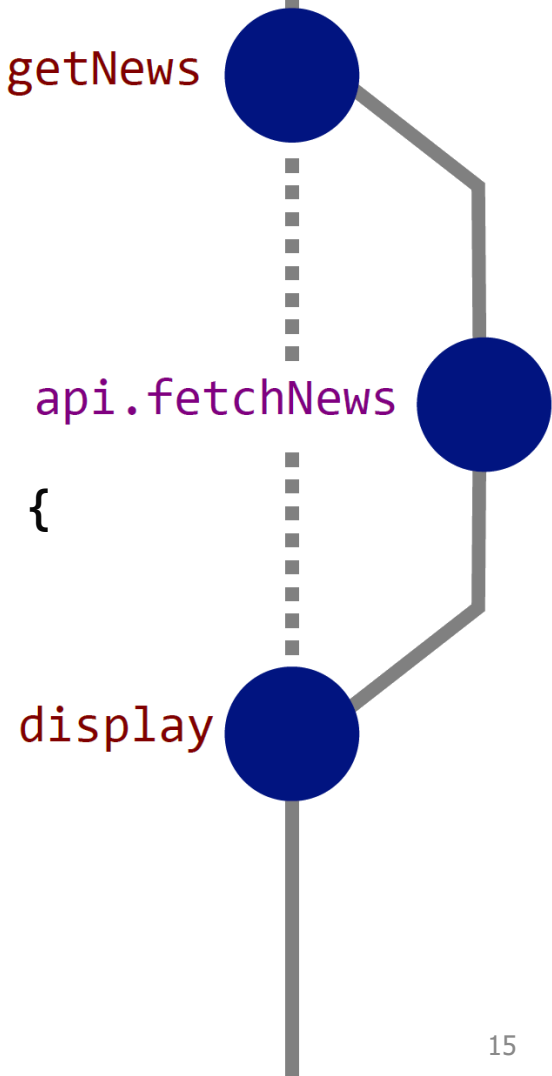
Thread vs. Coroutine



Source: https://www.youtube.com/watch?v=ShNhJ3wMpvQ

Async Programming with Coroutines

```
newsBtn.setOnClickListener {  // UI thread
    val news = getNews()
    display(news)
}
suspend fun getNews() = withContext(Dispatchers.IO) {
    return api.fetchNews()  // IO thread
}
```



Key benefit of Async Programming = ***Responsiveness***

prevent blocking the UI thread on long-running operations

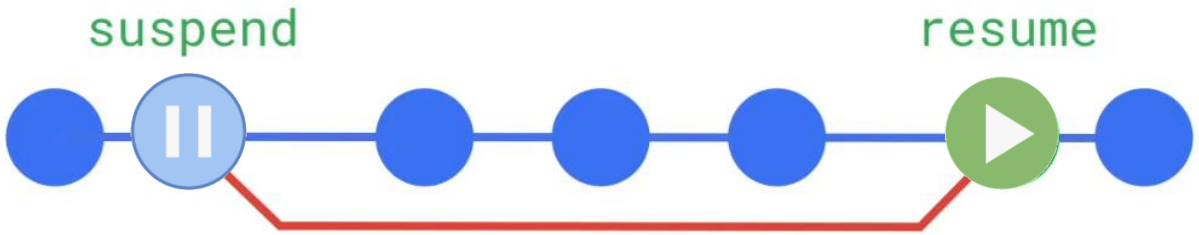
Callback vs. Coroutine

- Compared to callback-based code, coroutine code accomplishes the same result of unblocking the main thread **with less code**.
- Due to its sequential style, it's **easier to understand** + it's easy to chain several long running tasks without creating multiple callbacks

```
fun getUserOrders(username: String, password: String, callback: (List<Order>) -> Unit) {
    login(username, password) { user ->
        fetchOrders(user.userId) { orders ->
            // When the result is ready, pass it to main() using the callback
            callback(orders)
        }
    }
}
```

```
suspend fun getUserOrders(username: String, password: String) =
    withContext(Dispatchers.IO) {
        val user = login(username, password)
        val orders = fetchOrders(user.userId)
        return@withContext orders
    }
```

Coroutines Programming Model



Blocking vs. Non-Blocking (suspendable task)

- **Salat**  **vs.**  **Reading a Book** 

Mum: 📣 “Fatima comedown dinner ready!”

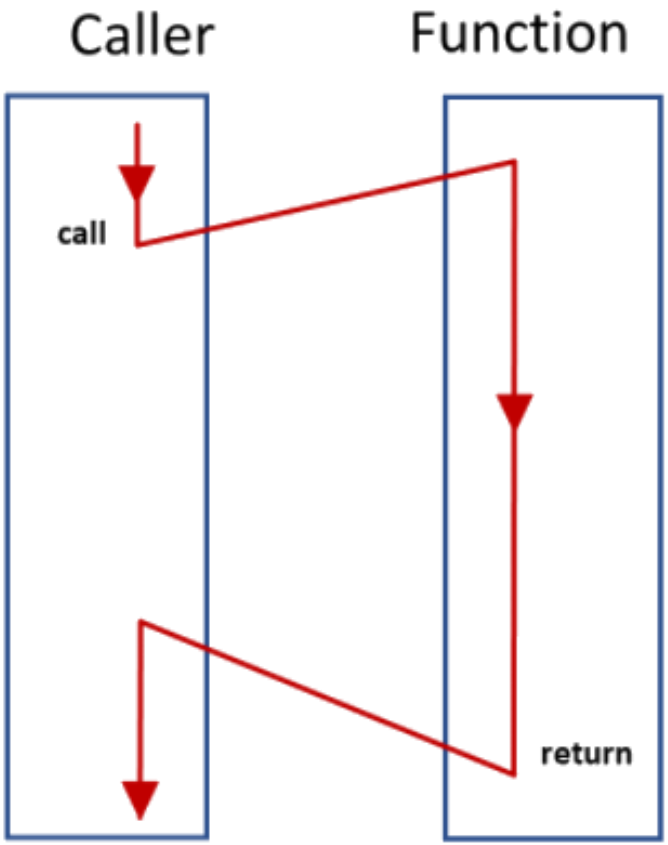
=> Salat is a **bocking** task. Wait to complete then you can do another task

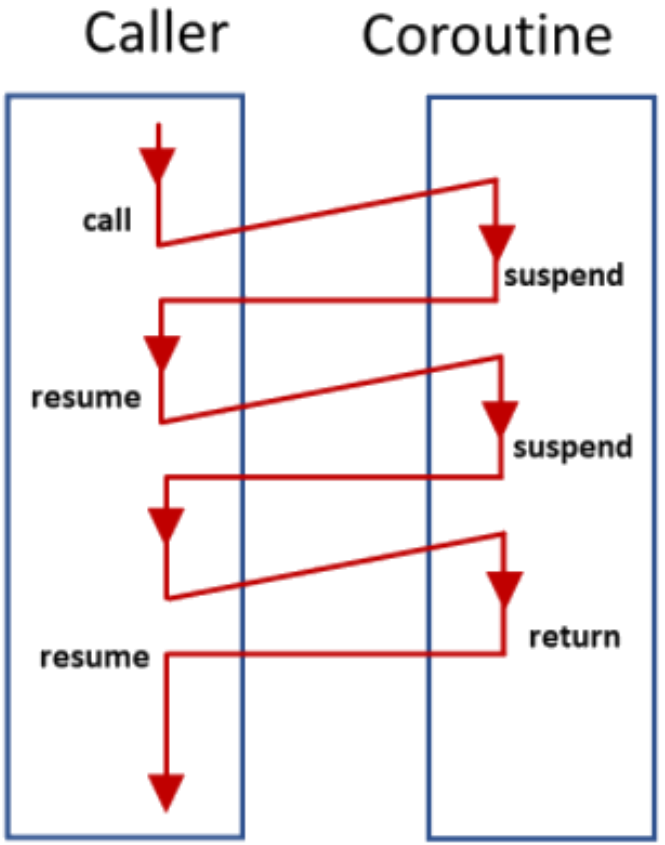
=> Reading a book is a task than can be **suspended** then **resumed**: add a bookmark, when ready resume reading from the bookmark

Suspend function

- **Suspend** function is a function that can be **suspended** and **resumed**
  - **suspend** is Kotlin's way of marking a function available to coroutines
- When a coroutine calls a function marked **suspend**, instead of blocking until that function returns:
  - it **suspends** execution until the result is ready then
  - it **resumes** where it left off with the result
- While it's suspended waiting for a result, **it unblocks the thread that it's running on** so other functions or coroutines can run

Function vs. Suspend Function





Suspend function can **suspend** at some points and later **resume** execution (possibly on another thread) when the return value is ready

To launch a Coroutine you need a Coroutine Scope

- A suspend function must be called in a coroutine
- A **Coroutine Scope** is required to create and start a coroutine using the scope's **launch** or **async** methods
- Coroutine Scope keeps track of child coroutines to allow the ability to cancel them and to handle exceptions
- Can be created as an instance of ***CoroutineScope***

```
val coroutineScope = CoroutineScope(Dispatchers.IO)
coroutineScope.launch { }
```

- On Android you could use provided scoped:
  - ***viewModelScope***, ***lifecycleScope***, ***rememberCoroutineScope***
  - GlobalScope is an app-level scope (rarely used). It lives as long as the app does

viewModelScope

- **viewModelScope** can be used in any ViewModel in the app
- Any incomplete coroutine launched in this scope is **automatically canceled** if the ViewModel is cleared (to avoid consuming resources unnecessarily)

```
class MyViewModel: ViewModel() {
    init {
        viewModelScope.launch {
            // Incomplete Coroutine will be canceled when the ViewModel is cleared
        }
    }
}
```

lifecycleScope

- **lifecycleScope** can be used in an activity
- Any incomplete coroutine launched in this scope is canceled when the Lifecycle is destroyed

```
class MainActivity : ComponentActivity() {
    override fun onCreate(savedInstanceState: Bundle?) {
        super.onCreate(savedInstanceState)

        lifecycleScope.launch {
         // Incomplete coroutines will be canceled when the activity is destroyed
        }
    }
}
```

LaunchedEffect

- `LaunchedEffect` should be used to execute some action when the **composable** is first launched
  - For example, requesting some data from the ViewModel
- With **LaunchedEffect**, you cannot control the lifecycle of the coroutine
  - The coroutine starts and ends based on the Composable lifecycle and has no way to manually cancel it

rememberCoroutineScope

- Use `rememberCoroutineScope` to create a **CoroutineScope** bound to the Composable lifecycle
  - If the composable leaves the recomposition, the coroutine will be cancelled automatically

```
/* Create a CoroutineScope that follows
   this composable's lifecycle */
val composableScope = rememberCoroutineScope()

composableScope.launch {
    //... your code
}
```

Coroutine builder functions

A coroutine scope offers two builder functions to **create** and **start** a coroutine

- **`launch`** **`Fire and forget`**

```
scope.launch(Dispatchers.IO) {
    loggingService.upload(logs)
}
```

- **`async`** **`Returns a value`**

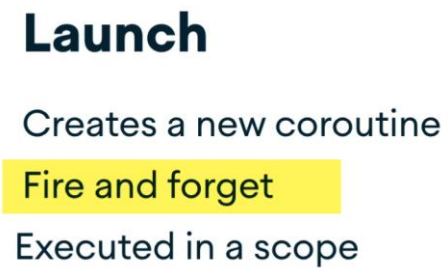
```
suspend fun getUser(userId: String): User =
    coroutineScope {
        val deferred = async(Dispatchers.IO) {
            userService.getUser(userId)
        }
        deferred.await()
    }
```

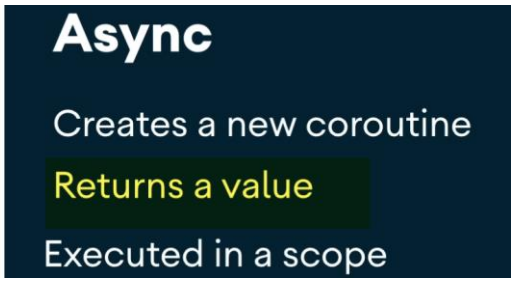
Launch vs. Async Coroutine builder functions

- **Launch** - Launches a new coroutine and returns a **job** which can then be used to **cancel** the coroutine
- **Async** — Launches a new coroutine and returns its future result (of type **Deferred**)

```
val deferred = async { viewModel.getStockQuote(company) }
```

  - Can use `deferred.await()` to suspend until the result is ready
  - Or call `deferred.cancel()` to cancel the coroutine





Parallel Execution of Coroutines

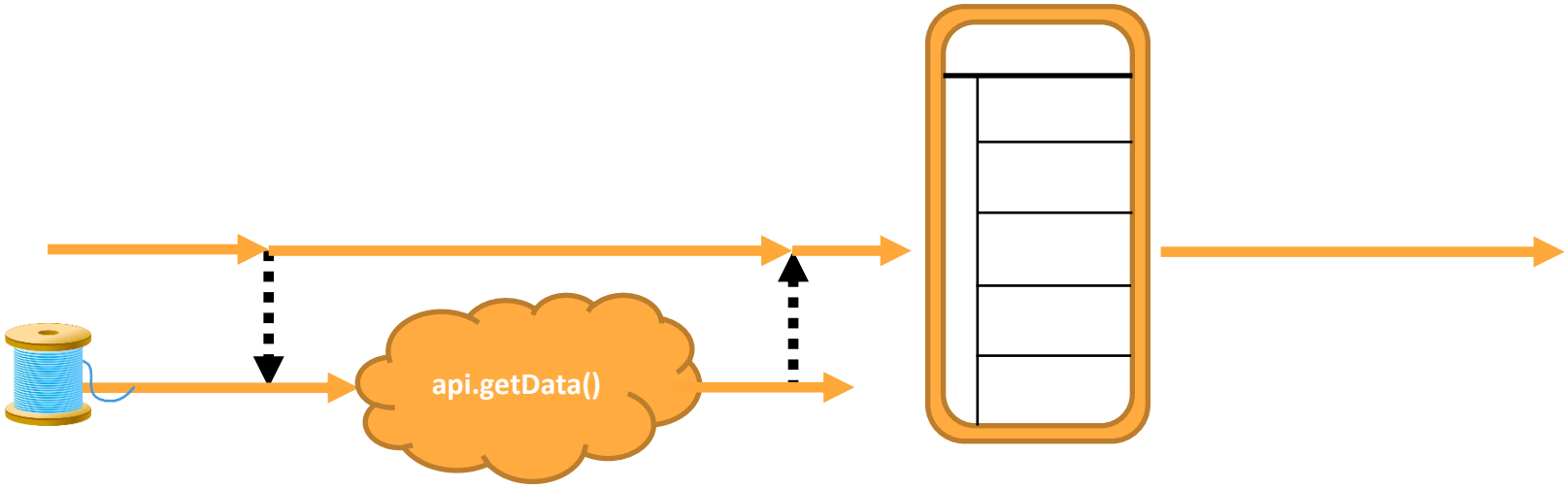
- Coroutines can be **executed in parallel** using **Async** or **Launch**
  - Parallelism is about doing lots of things simultaneously
- Async can await for the results (i.e. suspend until results are ready)

```
val deferred = async { getStockQuote("Apple") }
val deferred2 = async { getStockQuote("Google") }

val quote = deferred.await()
println(">> ${quote.name} (${quote.symbol}) = ${quote.price}")

val quote2 = deferred2.await()
println(">> ${quote2.name} (${quote2.symbol}) = ${quote2.price}")
```

Switch between threads



Perform fetch data on background thread then when the result is ready update the UI on Main thread

```
lifecycleScope.launch(Dispatchers.Default) {
    val value = fibonacci(1000)
    withContext(Dispatchers.Main) {
        resultStateVar = value.toString()
    }
}
```

Switch to Main Thread to update the UI state variable

Switch between threads

```
withContext(Dispatchers.?) {   ...   }
```

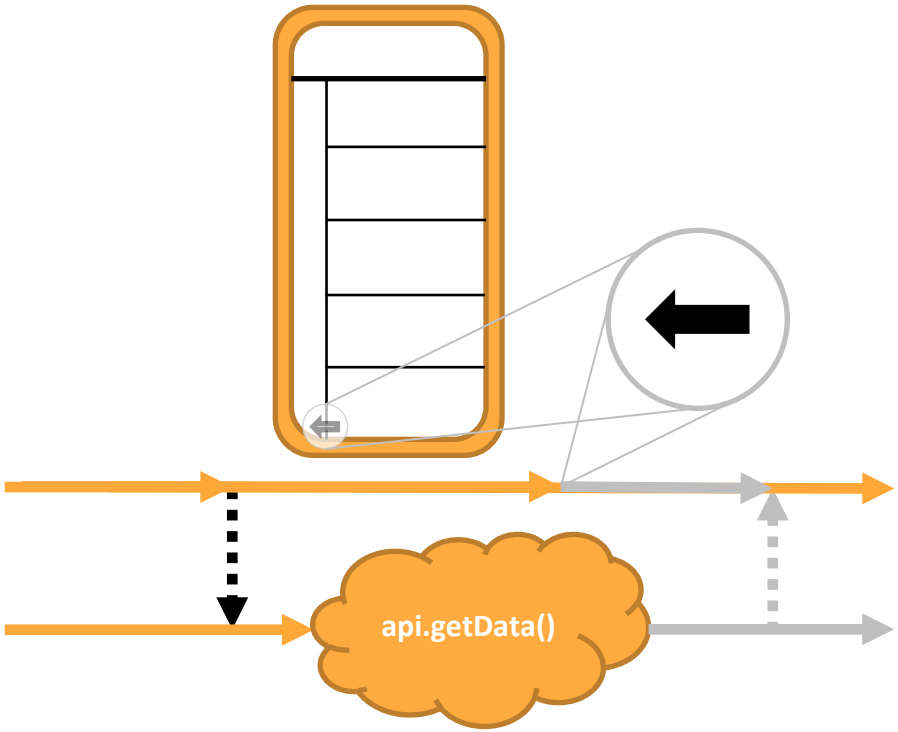
- **`withContext`** allows you to *decide where* do **want to run the computation**
- Use **`withContext`** to swap between different Dispatchers to execute computations on different threads:
  - **Dispatchers.IO**: Optimized for Network and Disk operations
  - **Dispatchers.Default**: used form CPU-intensive tasks
  - **Dispatchers.Main**: Used for updating the UI

Coroutine Cancelling

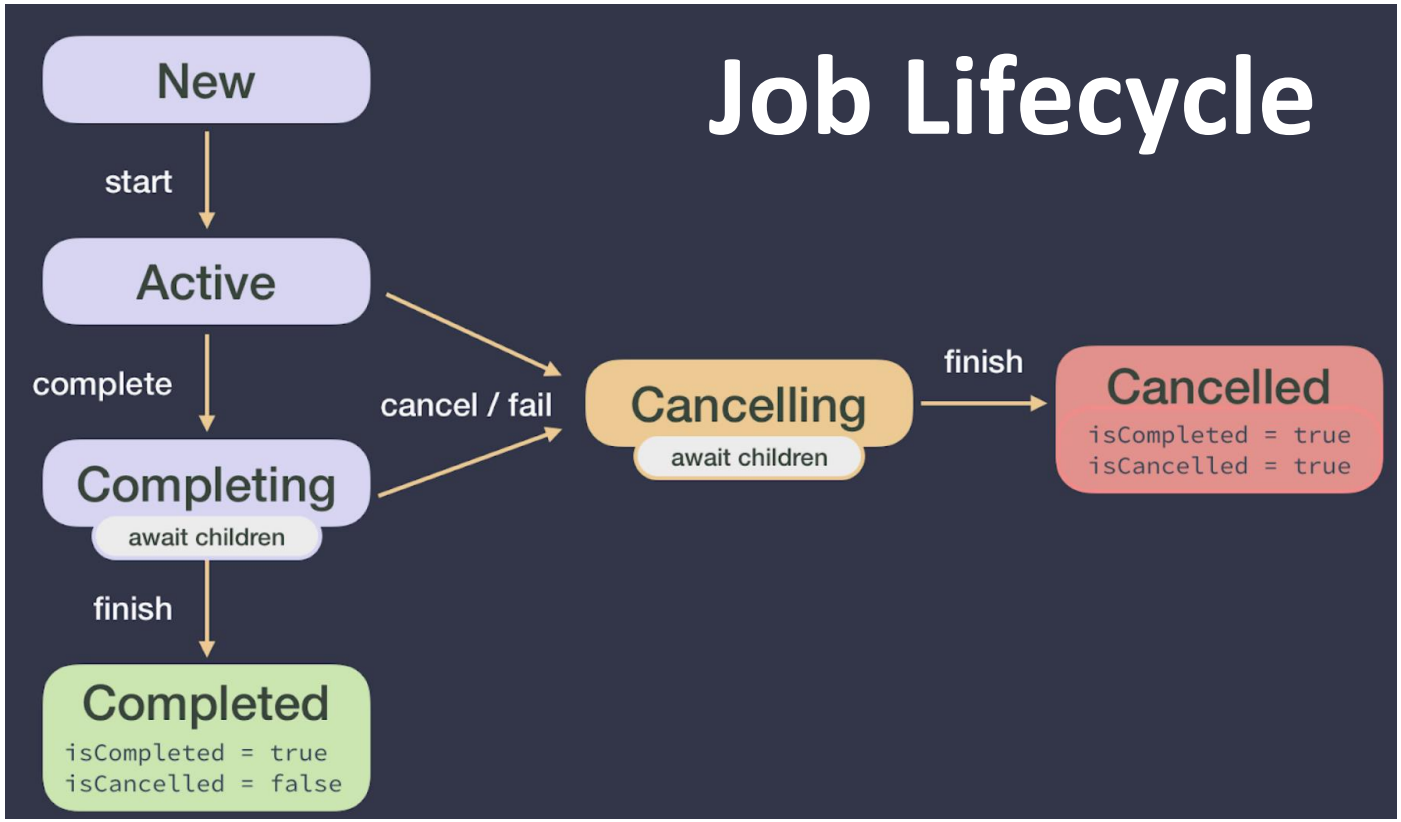
Coroutine Scope allows Structured Concurrency

- A coroutine **must** be **started in a Coroutine Scope.** This allows **Structured Concurrency** to:
  - Keep track of coroutines
  - Ability to cancel them
  - Is notified of failures (scope can cancel child coroutines if one of them fails)
- Coroutines started in the same scope form a **hierarchy** (scope is the parent and coroutines are children) having these properties:
  - A parent job **won't complete, until all its children have completed**
  - **Cancelling a parent will cancel all children**
  - Cancelling a child won't cancel the parent or siblings
  - If **a child coroutine fails**, the exception is propagated upwards, and **all the incomplete siblings are cancelled** (unless if a **supervisorScope** is used)

Coroutine Cancelling



- When the View is destroyed (e.g., Back Button pressed). How to cancel `api.getData()` task?
- Otherwise, **waste memory and battery life** + possible memory leak of UI that listens to the result of `getData()`




```
// Coroutine Scope enables Cancellation

val job = lifecycleScope.launch(Dispatchers.Default) {
    fibonacci()
}
...
// onCancel button clicked
job.cancel()
```

Coroutine Cancelling

```
// Create a coroutineScope and run multiple jobs
val scope = CoroutineScope(Dispatchers.IO)
val job1 = scope.launch { … }
val job2 = scope.launch { … }

// Cancelling the scope cancels its children
scope.cancel()

// Or you can cancel a particular job
// First coroutine will be cancelled and the other
// one won't be affected
job1.cancel()
```

```
val JOB_TIMEOUT = 5000L
// Cancel the job after 5 seconds timeout
// job will be null if the job is cancelled
val job = withTimeoutOrNull(JOB_TIMEOUT) {
    fibonacci().collect {
        print("$it, ")
    }
}
```

Exception Handling

Exception Handling

```
/*  By default, if one child failed the whole job is cancelled
     and all incomplete sibling jobs are cancelled.
     Unless supervisorScope is used (see example 12) */
val exceptionHandler = CoroutineExceptionHandler { context, exception ->
    println("Exception thrown somewhere within parent or child: $exception.")
}
val job = CoroutineScope(Dispatchers.IO).launch(exceptionHandler) {
    val deferred1 = async() { getStockQuote("Tesla") }
    try {
        val quote1 = deferred1.await()
    } catch (e: Exception) {
        println("Request failed : $e.")
    }
    val deferred2 = async() { getStockQuote("Aple") }
    try {
        val quote2 = deferred2.await()
    } catch (e: Exception) {
        println("Request failed : $e.")
    }
    val deferred3 = async() { getStockQuote("Google") }
    try {
        val quote3 = deferred3.await()
    } catch (e: Exception) {
        println("Request failed : $e.")
    }
}
```

Exception Handling with supervisorScope

```
/* Because the supervisorScope is used. If one child failed the whole job is NOT cancelled */
val exceptionHandler = CoroutineExceptionHandler { context, exception ->
    println("Exception thrown somewhere within parent or child: $exception.")
}
val job = CoroutineScope(Dispatchers.IO).launch(exceptionHandler) {
 supervisorScope {
    val deferred1 = async() { getStockQuote("Tesla") }
    try {
        val quote1 = deferred1.await()
    } catch (e: Exception) {
        println("Request failed : $e.")
    }
    val deferred2 = async() { getStockQuote("Aple") }
    try {
        val quote2 = deferred2.await()
    } catch (e: Exception) {
        println("Request failed : $e.")
    }
    val deferred3 = async() { getStockQuote("Google") }
    try {
        val quote3 = deferred3.await()
    } catch (e: Exception) {
        println("Request failed : $e.")
    }
 }
}
```

Resources

- Kotlin coroutines
  - https://kotlinlang.org/docs/reference/coroutines-overview.html
  - https://developer.android.com/kotlin/coroutines
- Part 1: Coroutines, Part 2: Cancellation in coroutines, and Part 3: Exceptions in coroutines
- Coroutines codelab
  - https://codelabs.developers.google.com/codelabs/kotlin-coroutines